Automatic Control and System Engineering Journal, ISSN 1687-4811, Volume 17, Issue 2, ICGST, Delaware, USA, December 2017

www.icgst.com

# An Innovative NXT Mobile Robot System for Landmine Detection

**Alaa Sheta and Mohammad Salamah**
Information Technology Department, Al-Balqa Applied University, Salt, Jordan
asheta2@yahoo.com, m.omar82@gmail.com

## Abstract

The current landmine detection technologies suf- fer many challenges on solving the humanitarian demining problem. Until now, detection and clearance in humanitarian demining very often relies on manual methods such as metal detector, as a primary procedure. The aim of this paper is to propose a multistage image processing methodology to detect the location of landmines in IR images. The method- ology count on the use of morphological image processing to detect the target mines. A database of images provided by the Royal Military Academy of Belgium was used to develop our results. The proposed MIP methodology was integrated with an NXT mobile robot, a smart N80 mobile phone and PC Server to test the developed software on a grid based environment. It was found that the proposed methodology and integrated system is very promising.

**Keywords:** Landmine detection, Morphological Operation, NXT Mobile Robot

## 1. Introduction

The development of demining technologies is a quite difficult and costly task. This is because of the wide range of terrains, which could be rocky, desert, beaches, muddy, river, forest, etc [1], [2]. It is important to mention that the climate conditions affect very much the available sensor technologies for landmine detection such as the Infrared (IR) technology [3]. IR technology is mostly affected by hot, humid, rainy, cold, windy conditions [4].

Humanitarian demining is a challenging process especially for the third world countries [5], [6]. To clear an area from mines, it requires that the removal process achieves a success ratio of 100%. The land should be free of mines with a high reliability and safety for human. Failure to do that will cost people life. The amount of time it takes to clear an area is less important than the safety of the clearance. Safety is with the highest importance. In military situation sometimes casualties are acceptable. This is not true in the case of civilians. We must also have a mechanism which results in no risks to those handling the demining task.

Thermal infrared cameras often used to detect landmines based on the assumption that landmines have different thermal properties than their surrounding soil. When an area is heated due to solar radiation, the landmines will warm up quicker than the soil. The soil above the landmine also warms up quickly. The influence of the landmine on the temperature of the soil at surface level relates to the burial depth. This situation, where landmines give relatively warm spots at the surface cause what is called *positive contrast*. When an area is cooled, for instance some time after sunset, the situation is reversed. Landmines will cause cold spots at the surface and cause what is called *negative contrast*.

## 2. Promising Sensor Technology

In April 2001, a report was written to the Chairman, Subcommittee on Military Research and Development, Committee on Armed Services, House of Representatives entitled, "Landmine Detaction DoD’s Research Program Needs a Comprehensive Evaluation Strategy". The committee objective was to evaluate the DoD’s strategy for identifying the most promising land mine detection technologies. The report stated:

> Improving DoD’s land mine detection capability is a challenging technological issue. Because of the threat that land mines pose to U.S. armed forces, you requested that we assess the abilities of competing technological options to address DoD’s mission needs for land mine detection. Specifically, our objectives were to determine whether DoD (1) employs an effective strategy for identifying and evaluating the most promising land mine detection technologies and (2) is investing in the most promising technologies to fully address mission needs.

The DoD search results show that: there are nine potentially promising technologies are funded by the DoD. They include: Acoustics/Seismic, Biosensors, Infraref/Multi-hyperspectral, LIDAR, Radar, Electromagnetic radiography, Passive millimeter wave, Terahertz imaging and X-ray fluorescence. These nine technologies proved to work in diverse environmental conditions with limited constraints related to soil types and water in soil.

Exploration of new technologies are being investigated to improve the reliability and speedup the detection op- eration, some of these technologies are Electromagnetic Induction Metal detectors (EMI) [7], Infrared Imaging, Ground-Penetrating Radar (GPR) [8], Acoustics, Thermal Neutron Activation (TNA), Photoacoustic Spectroscopy, Nu- clear Quadrupole Resonance (NQR), X-ray Tomography, Nneutron Back-scattering, Biosensors, Commercial sniffers, etc.

## 2.1 Infrared (IR) Imaging

IR radiation constitutes a portion of the Electromagnetic Spectrum (EM) domain. The frequency band of the EM waves is between 100 MHz and 100 GHz [9]. This is a fairly high frequency band. IR spectrum span in the wavelengths domain of 75μm and 1mm [9]. It is known that EM radiation produces heat. IR radiation can respond to the heat based on the type of material. Using EM to get the emission response represents a good source of infrared radiation.

IR has been used widely for handling the landmine detection problem. One drawback of IR imaging is that IR relies highly on the environment at the moment of measurement and the type of soil in the background. Infrared methods detect variations in electromagnetic radiation reflected or emitted by either the mines surface or the soil and vegetation located above the buried landmines [1].

IR imaging requires sensitive cameras with sufficient resolution. This technology measures landmines at a maximum burial depth of 10-15 cm [9]. In general the strength of infrared signatures is independent of the landmine class, and varies through the day. It is a day to day dependent process depending on environmental conditions such as solar loading, precipitation, and wind.

# 3. The Proposed MIP Methodology

Our objective is to detect the location of landmines in Infrared images using a Multistage Image Processing (MIP) methodology (see Figure 1) and integrated mobile robot system. Number of image processing methodlogies for landmine detection were proposed in [10], [11], [12]. The methodology starts by converting color image to gray scale. In the second stage, we select a suitable structuring element for performing morphological operation. We make image opening and closing on the gray scale image. In stage three, we check on the existence of objects in the image by selecting a suitable threshold level using our proposed methodology. By the end of this stage, we will be having a binary image with the detected object. In stage four, we label the connected components and use the Blob analysis technique to measure the properties for each labeled region [13].

## 3.1 Stage 1: Morphological Operations

Mathematical Morphology is a powerful tool for ex- tracting useful components from an image. Morphological image processing technique was provided in [14] at the Ecole des Mines in Paris. The technique was introduced as a set-theoretic method for image analysis which could help in extracting geometrical structures from an image. Using morphology, we can provide boundaries of objects, their skeletons, and their convex hulls [15]. It was also found useful in pre- and post-processing phases of image processing, especially in edge thinning and pruning [16], [17].

Morphological image processing is a collection of techniques for digital image processing based on mathematical morphology [18]. Morphology Operations are useful in the representation and description of region shape since these techniques rely only on the relative ordering of pixel values, not on their numerical values, they are especially suited to the processing of binary images and gray scale images. In this stage, it is important to select an appropriate structure element for the opening and closing processes. It will significantly help in separating the object from the background. Since we are searching for a landmine shape, we decided to use a structuring element S of a disk-shape [19].

## 3.2 Stage 2: Thresholding

Threshold is an important technique for image segmentation which helps to identify or extract a target from an image. Threshold can significantly help in achieving this goal if a proper threshold-level is chosen. The appropriate level helps to classify the foreground and the background. Pixels that have a value of intensity level greater than the threshold level will be classified as a foreground. Increasing the threshold level reduces the number of false alarms, but also leads to a lower detection rate [20].

In the past, number of threshold techniques was proposed.

In [21], image threshold method which combines various multi-scale and morphological features, including texture, shape and edge filtering by using genetic programming was presented. A faster version of Otsu's method was proposed for improving the efficiency of computation for the optimal thresholds of an image [22]. A survey over image threshold techniques and quantitative performance evaluation was presented in [23], [24] and novel parametric and global image histogram threshold method was presented in [25].

The proposed threshold technique can be summarized in the following steps (see Figure 2):

- Obtain the image histogram.
- Locate the points of minimum gray scale level and consider it as local minimum. In the case of an image with one target (see Figure 2), the global minimum between the two peaks will be selected as the thresholoding level. For an image with multiple minimum points (see Figure 3), we test all minimum levels till we locate our target.
- Remove all objects which have fewer than 100 pixels.
- Check if there is an object in the image, if not we tests another threshold level.

In Figure 3, we can see that the local minimum levels are located at the values 104, 122, 131, 153 and 159. Processing the image with the given threshold levels, we get the images provided in Figure 4 with landmine detected at level 159.

## 3.3 Stage 3: Feature Extraction

The binary large object (blob) is an area of connecting pixels with the same logical state. All pixels in an image that

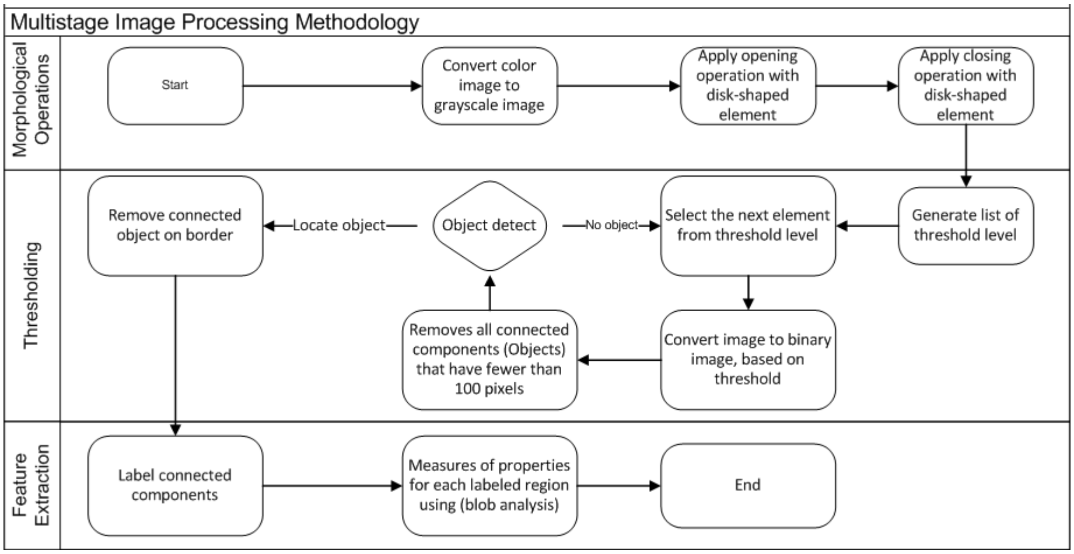



Fig. 1: A flow chart of the Multistage Image Processing (MIP) methodology

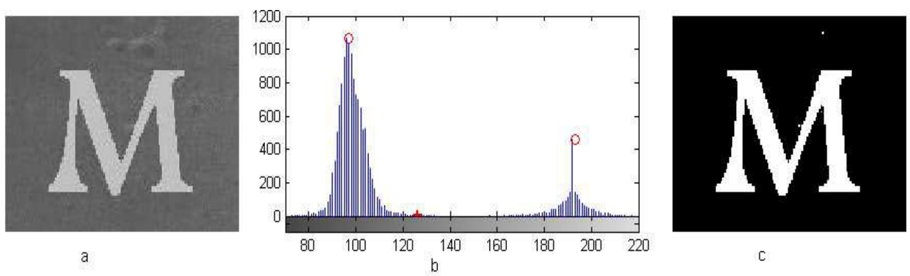



Fig. 2: (a) Original image with one object (b) Image histogram (c) Processed image with the object detected

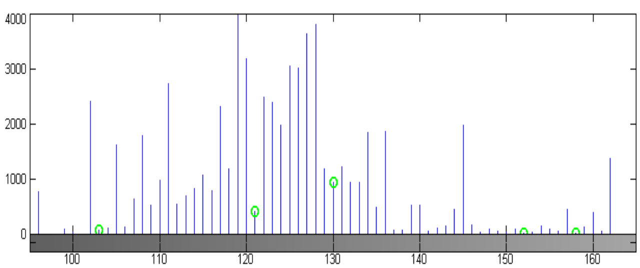


Fig. 3: Image histogram with multiple local minimum at levels 104, 122, 131, 153 and 159 of an IR image with landmine

belong to a blob are in a foreground class. All other pixels are in a background class. In a binary image, pixels in the background have values equal to zero while every nonzero pixel is part of a binary object [26]. Blob analysis is used to get 1) edges locations; 2) center location; 3) number of pixels in an object [13].

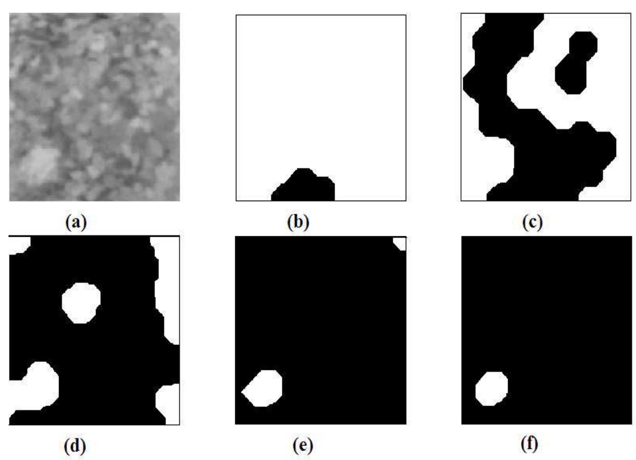



Fig. 4: (a) Original image. Processed IR image with threshold levels (b)104 (c)122 (d)131 (e)153 (f)159

## 4. Difficulties of Landmine Detection Using Robotics

A cheap and fast solutions based mobile robot system is urgently needed especially for landmine applications. Mine-seeking robots are still in the premature development stages. Currently, mobile robot systems are not flexible for their intended missions or can provide cost effective solution for mine detection and removal. This is why there is a need for newly designed robotics hardware and software systems which can be attractive to their missions. Some of the difficulties associated with using robotics for landmine detection was described in [2], [27] and can be summarized as follows:

- Most robotic equipment is extremely expensive to build, expensive to run and expensive to maintain.
- The robotics technology in the countries were landmine is buried is very low. The complexity of the robots sometimes makes it difficult to excite the end users about it.
- Many problems arises when we deal with sensitive applications such as the landmine problem. This is because most of laboratory robots are not qualified for real detection and clearing environment (i.e. vegetation, sand and mud).
- A multi-robot system or gent of robots could provide a fast and efficient solution to the problem although the development of a control system to manage and activity for such systems is a complex task [28].

## 5. Basic Requirement of a Robot System

In [27] author stated that:

> Before applying robotics technology for the mine clearance process, it is necessary to specify the basic requirements for a robot to have in order to achieve a better performance. These requirements include mechanisms, algorithms, functions and use.

These requirement was described in [27]. It can be itemized as follows:

- The robot should have a light weight not to active a landmine.
- The robot should have a simple design, flexible motion and highly reliable to accidents.
- The robot should be cheap to run, small, lightweight, and portable.
- The robot design should have adequate number of sensors to overcome obstacles and select a path.
- The robot should be able to recover problems which could happen during navigation and probing.
- The robot should be about to work in environment such as water, sand, temperature and humidity [29].
- The mechanical design of the robot should be simple for maintenance and repair.
- The robot high technology parts should be well protected.
- The robot power supply should enable the robot to operate for long period of time.
- The robot should have a remote control facility for tele-operation in landmine fields.

## 6. The Proposed Mobile Robot System

The demining process takes long time to accomplish and a minefield is one of the most dangerous regions. This paper proposes an integrated system which can speed up the process of mine detection and reduce risk than traditional manual methods for detection.

The proposed system relies on moving an NXT mobile robot to scan a minefield based on a developed grid environment of the mine field and detecting mines by using appropriate sensors attached to the mobile robot. The system developed a map of the area discovered, showing positions of located mines. The Proposed system consists of three devices as shown in Figure 5.

1) A PC Server is a Pentium 4 computer with a 512 RAM and support Wi-Fi connection. The PC Server is the brain for the whole system since it has the monitoring and the control system.
2) The LEGO NXT is the mobile robot which will be used to execute the mission. The NXT will hold the N80 mobile phone and navigate in the minefield.
3) N80 is a smart mobile phone device. N80 has an ARM-9 processor with clock rate of 220 MHz CPU, 18 MB RAM and Symbian OS v9.1 [1]. N80 include 3.0 Mega pixels camera and support for different type of wireless communications. They include (1) 3G network (384 kbps), (2) EDGE (286.8 kbps) (3) Bluetooth 2.0 and 4) WLAN 802.11b/g (See Figure 6).

The proposed system assumes we can have an IR camera to be carried on the mobile robot. We suggest the use of the 400DX IR camera to be attached to a PDA and used as a mobile wireless IR camera. The developed environment for our experimentation is shown in Figure 7. We considered the environment as a grid of steps each of which with a fixed selected size depending on the size of the mine field. A software system for the MIP was developed to apply the proposed MIP methodology. The user interface of the software is presented in Figure 8. The software was developed using MATLAB programming language.

## 7. Experimental Results

Our objective is to detect landmine from IR images using a proposed MIP methodology and integrated mobile robot

[1] Symbian OS is a proprietary operating system, designed for mobile devices, with associated libraries, user interface frameworks and reference implementations of common tools, produced by Symbian Ltd. It is a descendant of Psion's EPOC and runs exclusively on ARM processors [30]

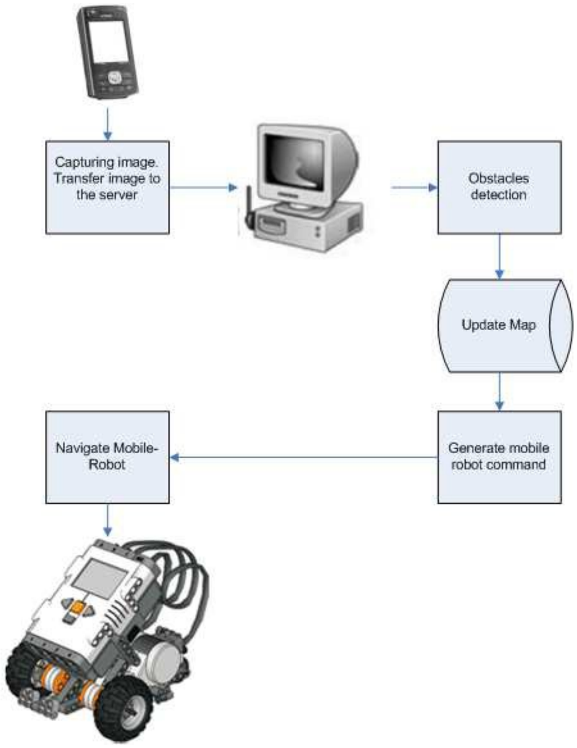



Fig. 5: The proposed mobile robot system

system. As we mentioned, there is normally a difference between the grayscale of the landmine and the grayscale of the soil.

We run our experiment on real images provided by the Royal Military Academy of Belgium, Belgium of MWIR. The MWIR database provides 136 IR images for both *sand* and *grovel* soils [31]. These images were collected at Meerdael (Belgium) minefields on 1$^{st}$, 2$^{nd}$ and 3$^{rd}$ of April 1998 using mid-wave infrared cameras - AGEMA (3μm-5μm).

In Figure 9 and Figure 10, we show the original IR images with landmine, the corresponding histogram of the image and the image processed using the proposed MIP methodology. The two images where taken in a sand soil at the time 13:08 and 22:04, respectively.

We applied our proposed methodology on two images with a gravel soil background. The results of the image processing methodology is presented in Figure 11 and Figure 12. The two images were taken at the time 12:18 and 22:04, respectively. The developed results in the two soil environment was compared by the results provided by [32]. The location of the landmine was verified successfully. The proposed threshold level was selected appropriately. This means that the proposed methodology works well with both the day and evening time images.

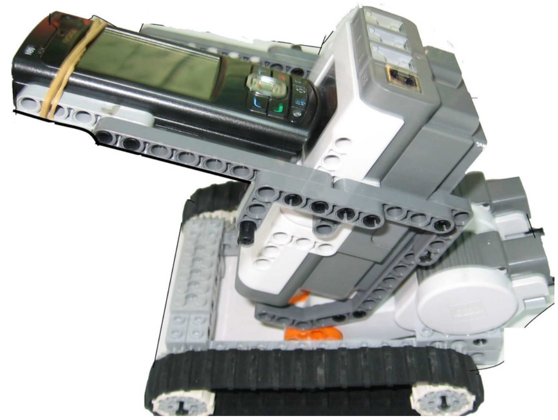


Fig. 6: An N80 mobile phone fixed on the NXT robot

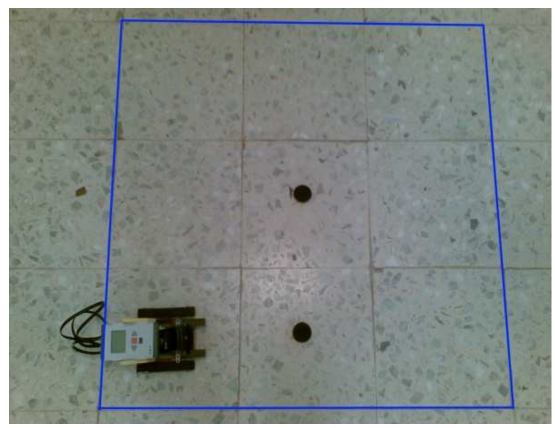
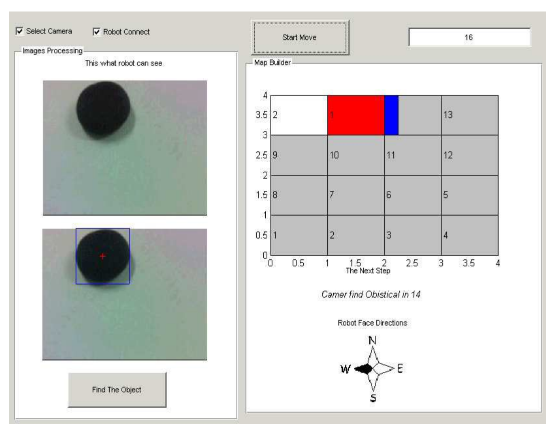


Fig. 7: The environmnet for the experimentation Fig.




8: The developed software interface

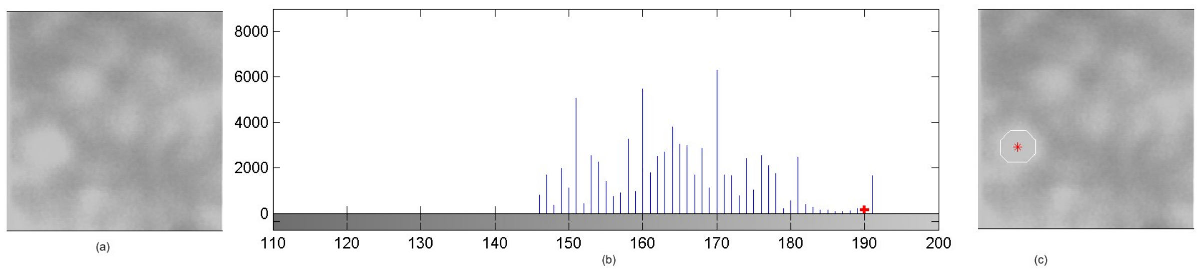



Fig. 9: (a) Original IR image on a sand soil taken at a time 13:08 (b) Image histogram (c) Processed image with mine detected

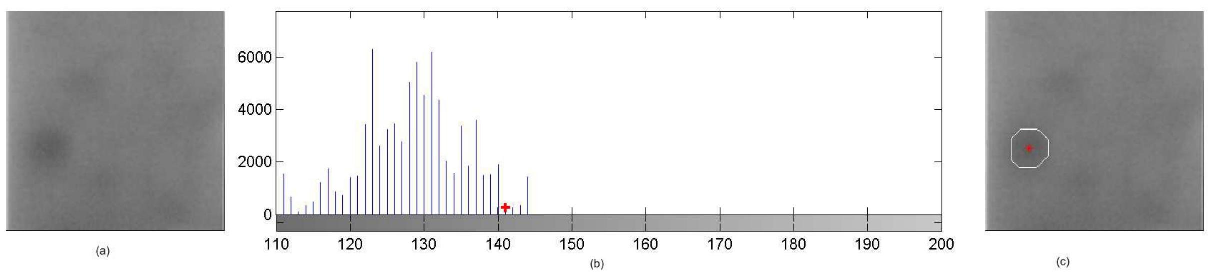



Fig. 10: (a) Original IR image on a sand soil taken at a time 22:04 (b) Image histogram (c) Processed image with mine detected

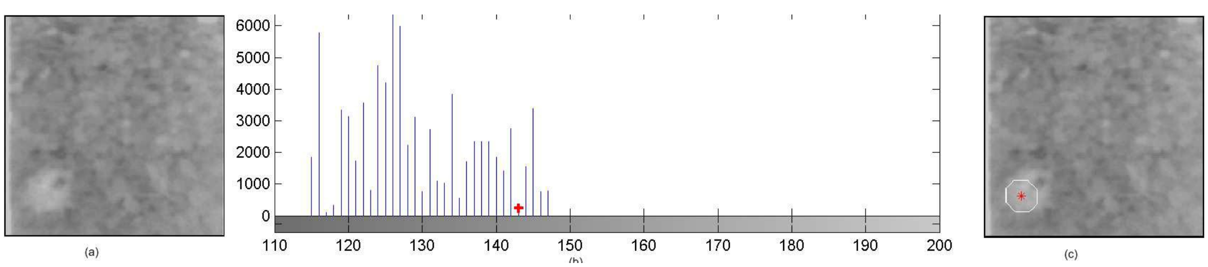



Fig. 11: (a) Original IR image on a gravel soil taken at a time 12:18 (b) Image histogram (c) Processed image with mine detected

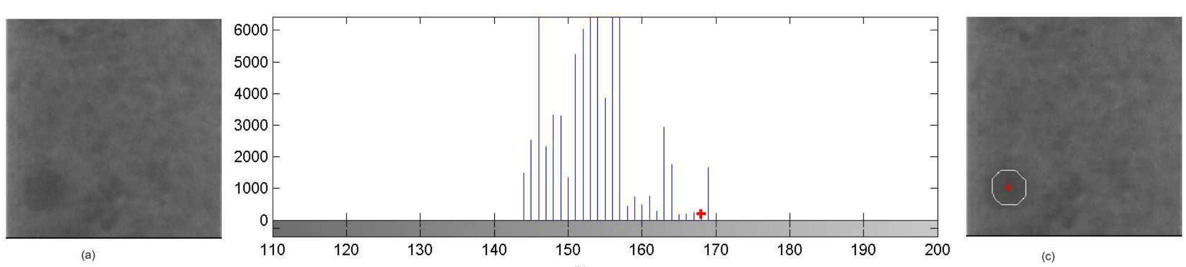



Fig. 12: (a) Original IR image on a gravel soil taken at a time 21:19 (b) Image histogram (c) Processed image with mine detected

## 8. Conclusions

In this paper, we provided a multi-stage image processing technique which uses morphological image processing to locate landmine in infrared image. The proposed MIP methodology was integrated with a mobile robot system for testing purposes. The process starts by converting color image to gray scale, select suitable structuring element for performing morphological operation, pick up a suitable threshold level to locate the landmine object, produce a binary image with the detected object. Finally, the target is labeled and located. The developed results were verified according to [32] with correct the correct mine locations detected. The developed results show that this system can be expanded with appropriate hardware facility to work in real landmine fields.

## References


[1] S. ho Hong, T. Miller, H. Tobin, B. Borchers, J. M. H. Hendrickx, H. Lensen, P. Schwering, and B. Baertlein, "Impact of soil water content on landmine detection using radar and thermal infrared sensors, detection and remediation technologies for mines and minelike targets VI," in Detection and Remediation Technologies for Mines and Minelike Targets, 2001, pp. 409–416.

[2] M. K. Habib, "Mine clearance techniques and technologies for effective humanitarian demining," International Journal of Mine Action, vol. 6, no. 1, 2002.

[3] W. D. Jong and K. Schutte, "Processing of polarimetric infrared images for landmine detection," in Proceedings of the 2nd International Workshop on Advanced Ground Penetrating Radar (IWAGPR), 2003.

[4] B. N. Nelson, "Region of interest identification, feature extraction, and information fusion in a forward looking infrared sensor used in landmine detection," in Proceedings of the IEEE Workshop on Computer Vision Beyond the Visible Spectrum: Methods and Applications (CVBVS 2000). Washington, DC, USA: IEEE Computer Society, 2000, p. 94.

[5] C. Bruschini, K. D. Bruyn, H. Sahli, and J. Cornelis, EUDEM: The EU in Humanitarian DEMining. EU report, Brussels, 1999.

[6] S. Burke, "The u.s. department of defense humanitarian demining research and development program," Journal of Mine Action, vol. 7, no. 1, 2003.

[7] C. P. Gooneratne, S. C. Mukhopahyay, and G. S. Gupta, "A review of sensing technologies for landmine detection:unmanned vehicle based approach," in Proceedings of the 2nd International Conference on Autonomous Robots and Agents, December 13-15, 2004 Palmerston North, New Zealand, 2004, pp. 401–407.

[8] R. Harman, J. Holloway, and J. Broach, "Detection and remediation technologies for mines and minelike targets," in Proceeding of the SPIE, 2003.

[9] L. Kempen, "Physical principals for anti-personal mine detection: A survey of three sensing principals," Technical Report IRIS-TR-0047, Department of Electronics and Information Processing, Vrije Universiteit Brussel, Tech. Rep., 1997.

[10] M. Salameh, "Analysis and design of a landmine detection system using mobile devices," Master's thesis, Al-Balqa Applied University, 2008.

[11] A. Ajlouni, "Improving landmine detection process using image processing techniques," Master's thesis, Al-Balqa Applied University, 2008.

[12] A. Ajlouni and A. Sheta, "Landmind detection with IR sensors using karhunen loeve transformation and watershed segmentation," in The 5th IEEE International Multi-Conference on Systems, Signals and Devices, 2008, pp. 1–6.

[13] T.-H. Chen, Y.-F. Lin, and T.-Y. Chen, "Intelligent vehicle counting method based on blob analysis in traffic surveillance," Proceedings of The Second International Conference onInnovative Computing, Information and Control (ICICIC '07), pp. 238–238, 2007.

[14] J. Serra, Image Analysis and Mathematical Morphology. Academic Press, 1982.

[15] P. Brigger and J. R. Casas, "Morphological operators for image and video compression," IEEE Trans. on Image Processing, vol. 5, pp. 881–897, 1996.

[16] N. J. Leite and S. J. F. Guimaräes, "Morphological residues and a general framework for image filtering and segmentation," EURASIP J. Appl. Signal Process., vol. 2001, no. 1, pp. 219–229, 2001.

[17] K. Mikula, T. Preusser, and M. Rumpf, "Morphological image sequence processing," Comput. Vis. Sci., vol. 6, no. 4, pp. 197–209, 2004.

[18] R. C. Gonzalez, R. E. Woods, and S. L. Eddins, Digital Image Processing Using MATLAB. Upper Saddle River, NJ, USA: Prentice-Hall, Inc., 2003.

[19] D. Schonfeld, "Optimal structuring elements for the morphological pattern restoration of binary images," IEEE Trans. Pattern Anal. Mach. Intell., vol. 16, no. 6, pp. 589–601, 1994.

[20] W. Messelink, K. Schutte, A. Vossepoel, F. Cremer, J. Schavemaker, and E. den Breejen, "Feature based detection of landmines in infrared images," in Proceeding on the SPIE Conference, Detection and Remediation Technologies for Mines and Minelike Targets VII, J. T. Broach, R. S. Harmon, and G. J. Dobeck, eds.,(Orlando (FL), USA), vol. 4742, 2002, pp. 108–119.

[21] J. Hervas and P. L. Rosin, "Image thresholding for landslide detection by genetic programming," in Proceedings of the First International Workshop on Multitemporal Remote Sensing Images, L. Bruzzone and P. Smits, Eds. University of Trento, Italy: World Scientific Publishing, 13-14 Sept. 2001.

[22] P. sung Liao, T. sheng Chen, and P. choo Chung, "A fast algorithm for multilevel thresholding," Journal of Information Science and Engineering, vol. 17, pp. 713–727, 2001.

[23] P. L. Rosin and E. Ioannidis, "Evaluation of global image thresholding for change detection," Pattern Recogn. Lett., vol. 24, no. 14, pp. 2345–2356, 2003.

[24] M. Sezgin and B. Sankur, "Survey over image thresholding techniques and quantitative performance evaluation," Journal of Electronic Imaging, vol. 13, pp. 146Ű–165, January 2004.

[25] Y. Bazi, L. Bruzzone, and F. Melgani, "Image thresholding based on the EM algorithm and the generalized gaussian distribution," Pattern Recogn., vol. 40, no. 2, pp. 619–634, 2007.

[26] N. I. Corporation, "Image analysis and processing," http://zone.ni.com/devzone/cda/tut/p/id/3470, Sep 6, 2006, [Online; accessed 6-February-2008].

[27] M. K. Habib, "Humanitarian demining: Reality and the challenge of technology-the state of the arts," International Journal of advances Robotic systems, vol. 4, no. 2, 2007.

[28] P. Santana, J. Barata, O. Cruz, A. Mestre, J. Lisboa, and L. Flores, "A multi-robot system for landmine detection," in Proceedings of the 10th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2005, 2005, pp. 721–728.

[29] H. Goldenberg, H. Najjaran, N. Kircanski, and A. A. Goldenberg, "Landmine detection using an autonomous terrain-scanning robot," International Journal of Industrial Robot, vol. 32, pp. 240–247, 2005.

[30] Nokia, "Forum nokia website," http://www.forum.nokia.com/, 2007.

[31] K. Willekens, "Meerdael (belgium) minefields images," http://apl-database.jrc.it/Home/Optical-IR/Non-JRC/RMA_Meerdael/, December 20 1999, [Online; accessed 6-February-2008].

[32] M. Acheroy, D. Milojevic, Y. Yvinec, A. Pizurica, L. VanKempen, and N. Milisavljevic, "HUDEM IR trials at meerdael," http://www.sic.rma.ac.be/ nada/Meerdael.html, April 1-4, 1998, [Online; accessed 6-February-2008].

## Biography

Alaa F. Sheta received his B.E., M.Sc. degrees in Electronics and Communication Engineering from the Faculty of Engineering, Cairo University in 1988 and 1994, respectively. He received his Ph.D. degree from the Computer Science Department, School of Information Technology and Engineering, George Mason University, Fairfax, VA, USA in 1997. He was promoted to professorship in 2008. Currently, Prof. Sheta is a faculty member with the Computer Science Department, The World Islamic Sciences and Education (WISE) University, Amman, Jordan. He is on leave from the Computers and Systems Department, Electronics Research Institute (ERI), Cairo, Egypt. He published over 80 papers, book chapters and two books in the area of image processing and evolutionary computations. He has been an invited speaker in number of national and international conferences. Prof. Sheta is a member of the IEEE Evolutionary Computations, ACM and ISAI societies. He is also the Vice President of the Arab Computer Society (ACS). His research interests include Evolutionary Computation, Modeling and Simulation of Dynamical Nonlinear Systems, Image Processing, Robotics, Swarm Intelligence, Automatic Control, Fuzzy Logic, Neural Networks and Software Reliability Modeling.